Adagio for Color Fields

Adagio for Color Fields is a generative audio-visual installation that induces *synesthesia*. The eyes and ears receive precisely synchronized content that may be experienced as seeing music, hearing color, or both. The installation is controlled by a computer that uses a single algorithm to generate audio and video in real time. The audio consists of orchestral string music, while the video consists of continuously changing color gradients. The music and colors evolve identically because they are the same data expressed in two different media at once. The data comes from oscillators tuned to slightly different frequencies, hence the installation is a type of *phase art*.

Musically, the installation modulates through major keys in the cycle of fourths. Each complete cycle through all twelve keys takes approximately eight minutes, after which a silent pause occurs. No two cycles are exactly alike, because the algorithm's state is randomized at the start of each cycle.

History

Adagio for Color Fields evolved from a series of earlier works, including *Planets* (1994), *Al Fasawz* (2003), *Whorld* (2005), *Plasmagon* (2009), and *TripLight* (2015). All of these works generate content from phasing, and it is instructive to compare them.

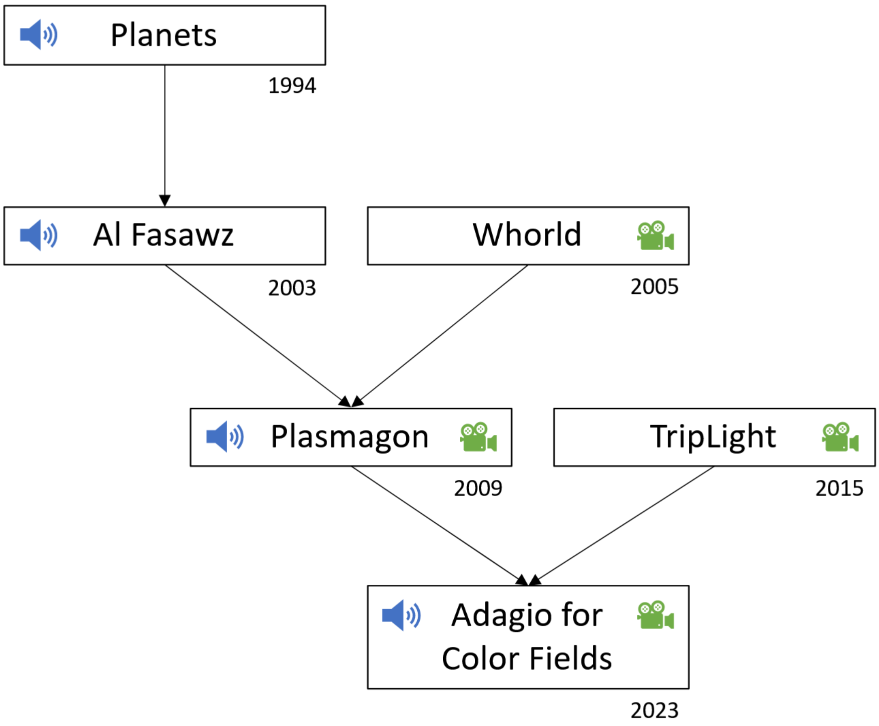

Figure 1: Ancestry of *Adagio for Color Fields*.

Planets

Planets is a musical composition that models the motions of the planets in our solar system. Each planet is represented by a sustained tone that varies in loudness according to the planet's position within its orbit, also known as its *phase*. More succinctly, orbital phase is mapped to volume.

Viewed from above, the solar system can be visualized as concentric rings, one for each planet. A planet starts at the bottom of its ring, with its corresponding tone silent. As the planet circles, its tone gets louder, and reaches maximum volume when the planet reaches the top of its ring. After the planet passes the top, its tone gets quieter again, and finally returns to silence at the bottom of the ring, where the cycle restarts.

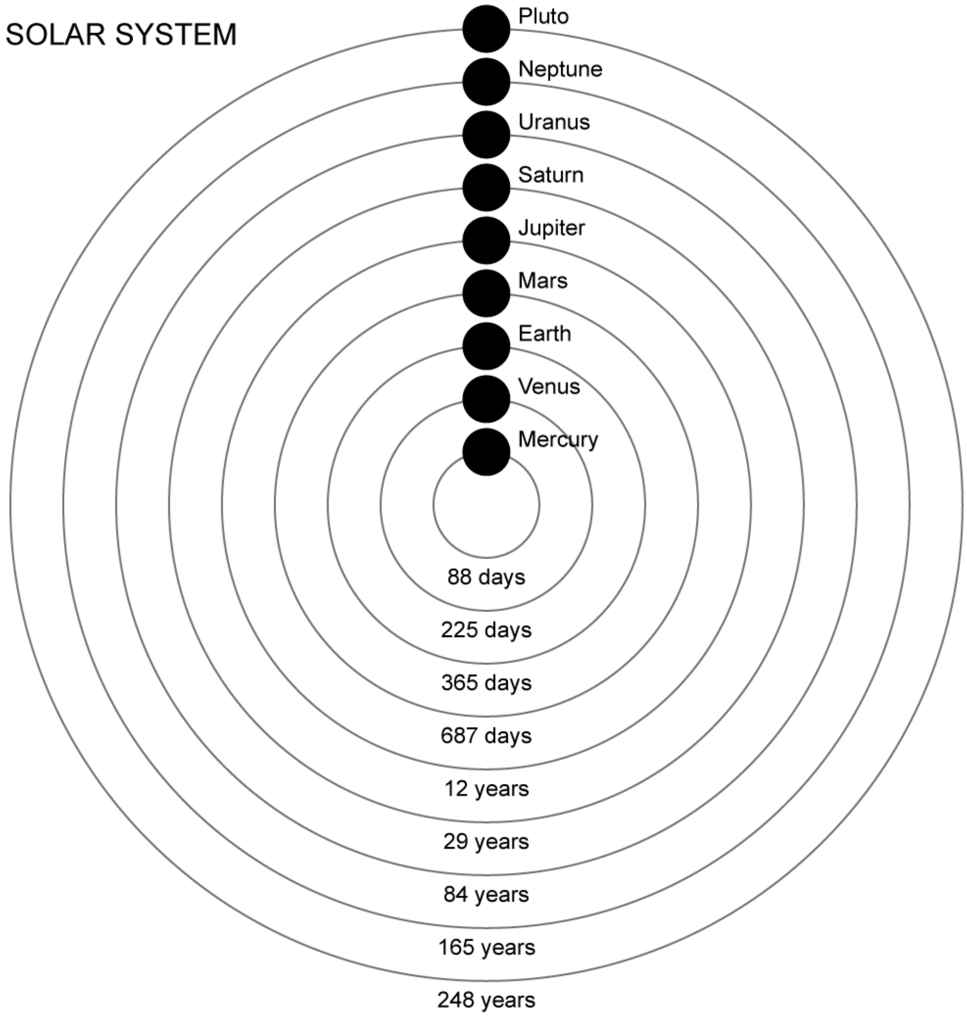

Figure 2: Solar system as rings, with planets in full convergence.

Each of the planets orbits the sun at a different speed. These speeds are much too slow to be musically useful, and therefore must be rescaled to a perceivable range. In reality, the outermost planet takes 248 years to complete one orbit, but in the composition, that period is compressed to fifteen minutes, and the other planets are speeded up proportionally, so that the innermost planet orbits roughly once per second.

Each planet’s initial phase is set so that halfway through the composition, all of the planets line up and reach maximum volume simultaneously. This momentary alignment in which all the orbits have the same phase is known as a *convergence*. Convergence is a crucial aspect of phase art. Note that in the actual solar system, a full convergence of all the planets is extremely improbable, though partial convergences involving a subset of the planets occur regularly.

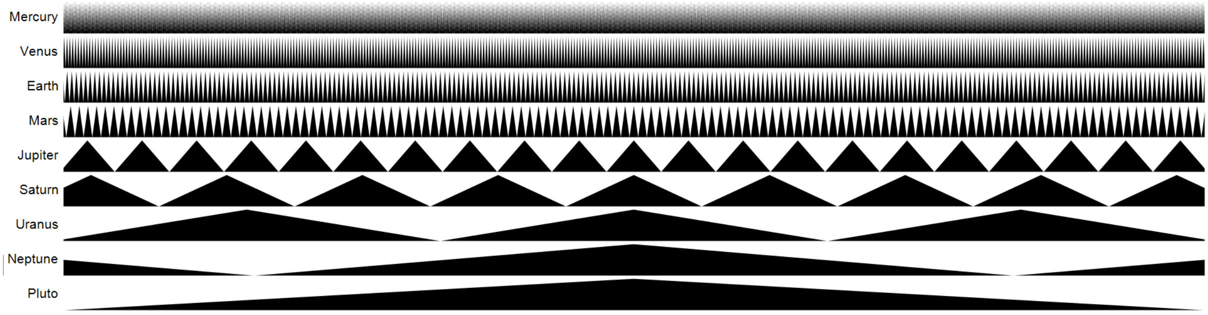

Figure 3: Phase diagram for *Planets*, showing full convergence in the middle.

The composition greatly simplifies the planetary orbits, by reducing them to a series of oscillators, one per planet. The oscillators all have different frequencies, which is an essential prerequisite for phasing. Each oscillator outputs a periodic waveform—in this case a triangle wave—which causes a sustained tone to fade in and out repeatedly. These features recur in subsequent works.

Al Fasawz

Al Fasawz is a musical composition inspired by the sound of breaking waves at Halibut Point in Rockport, Massachusetts. The composition consists of six sustained tones that form a chord, specifically a C minor ninth chord with a minor sixth. This chord is conventional compared to *Planets*, which uses a cycle of pure fifths, also known as Pythagorean tuning.

As in *Planets*, each tone is modulated by an oscillator, but instead of modulating the tone's loudness, the oscillator modulates the tone's harmonic content, by varying the cutoff frequency of a low-pass filter. Filtering affects loudness non-linearly, and to compensate for that, the oscillators output sine waves, unlike the *Planets* oscillators which output triangle waves.

Whereas *Planets* is monophonic, *Al Fasawz* spreads its tones widely in the stereo image, in order to simulate the stereophonic experience of hearing coastal surf. This innovation significantly enhances the perception of phasing, and recurs in subsequent works.

The phase pattern of *Al Fasawz* repeats after 354 days. This is the time between full convergences, and it can be determined precisely because the oscillators used in *Al Fasawz* all have small integer periods. The periods used in *Planets* aren't integers and cover a huge range, hence the repeat time of *Planets* can only be approximated; four trillion years is a reasonable estimate.

All of the phase compositions we consider avoid percussive attacks by continuously fading tones in and out. This lack of edges permits gradated chord changes, another innovation in *Al Fasawz*. As the minor sixth (A flat) gets louder, the chord begins to sound more like F minor than C minor, but there is no detectable boundary, thus the harmony is often ambiguous and indeterminate.

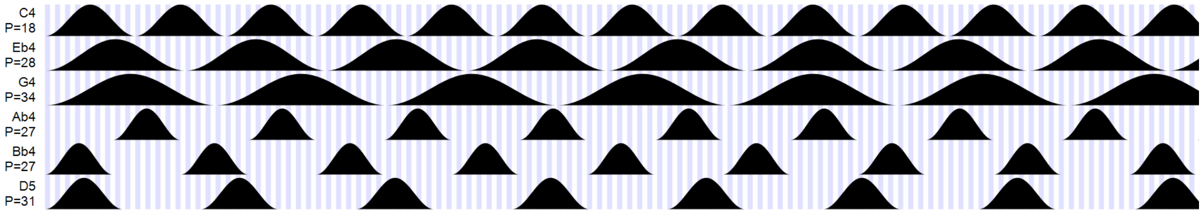

Figure 4: Phase diagram for *Al Fasawz*. The captions list each oscillator's musical pitch and period.

Al Fasawz also introduces an algorithmic “listener” that monitors the output of the oscillators and potentially alters the composition in response to their behavior. The listener examines the future output, searching for volume peaks that exceed a defined threshold. If the listener finds a suitable peak, it fades in a bass note, timed to coincide with and accentuate the peak. This is an example of lookahead feedback.

Plasmagon

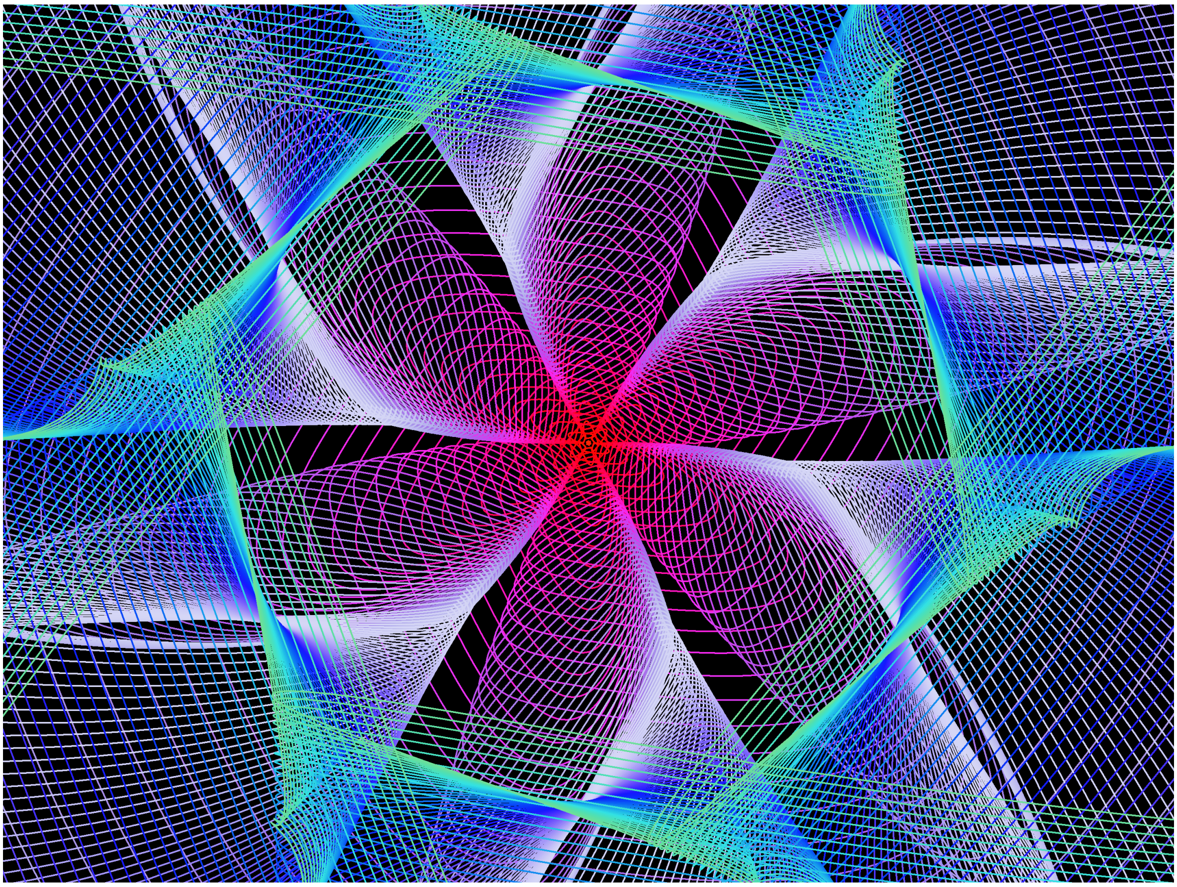

Figure 5: Snapshot of *Whorld* running the *Plasmagon* patch.

Plasmagon evolved from *Whorld*, a geometric visualizer and VJ software. *Whorld* responds to parameters that can be controlled by oscillators, and in *Plasmagon* these oscillators also control the volume of musical tones. Because the music and visual are identically modulated, their motions are tightly coupled and may induce synesthesia. *Plasmagon* adds synchronized music to a preexisting phase-based visual software to produce a synesthetic audiovisual installation, and this same evolution recurs in *Adagio for Color Fields*.

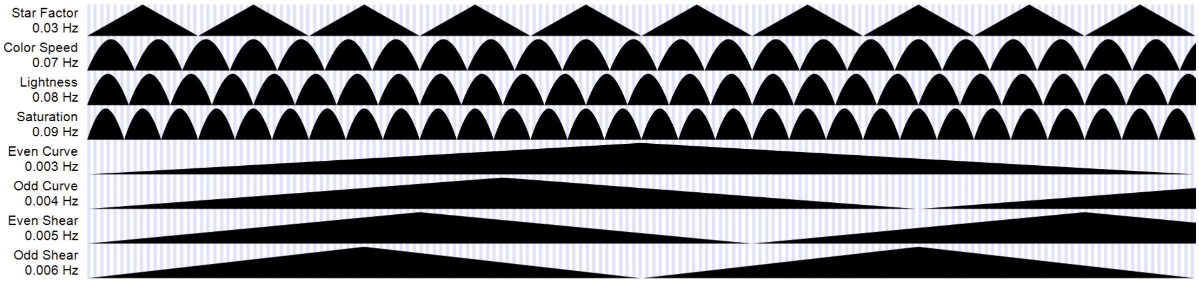

Figure 6: Phase diagram for *Plasmagon*. The captions list each oscillator’s target *Whorld* parameter and frequency in Hertz.

As in previous works, tones always fade in and out gradually, and this lack of edges results in continuous harmonic gradation instead of distinguishable chords. However unlike previous works which maintain a fixed set of tones throughout, varying only their proportions, in *Plasmagon* the set of tones also varies over time. It changes in two ways: by alternating between adjacent scale tones, and less frequently, by changing which notes the scale is composed of, also known as changing key.

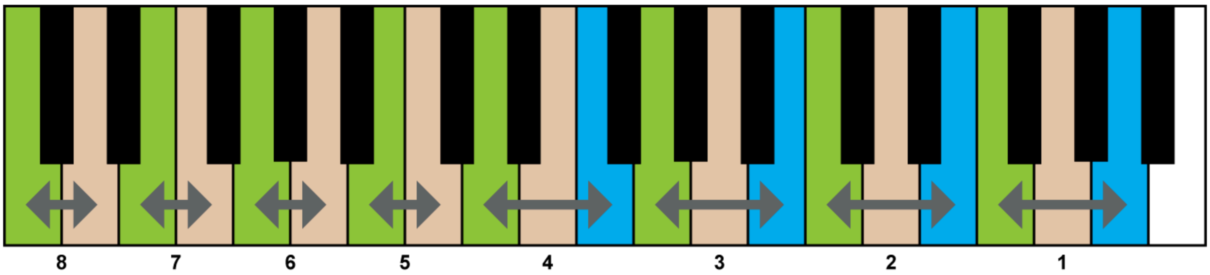

Figure 7: Scale tone alternation in *Plasmagon*. Some channels alternate between two adjacent tones, while others alternate between three.

To change key without unintended dissonance, all of the affected notes must be altered simultaneously. This is nontrivial in *Plasmagon* because altering the pitch of audible notes would introduce incongruous glitches, and each note fades in and out at a different rate. To ensure that a key change is perfectly smooth, it must occur at a moment when all of the affected notes are silent. As in *Al Fasawz*, the solution is an algorithmic “listener.” In *Plasmagon*, the listener monitors the oscillator phases and defers changing key until a suitable opportunity arises. This technique is called “stealth modulation,” and the elapsed time between key changes necessarily varies because of it.

Unlike previous works which use basic synthesized sounds such as sine or sawtooth waves, *Plasmagon* uses choral vocal samples for enhanced fidelity and realism. *Plasmagon* also has a relatively short repeat time, reaching full convergence after only seven and a half hours.

TripLight

TripLight is a color organ derived from continuously changing color gradients. It takes advantage of the fact that modern computers can render gradient triangles very quickly with little CPU overhead. Rendering one hundred times a second is feasible, and at that rate even rapid color changes appear acceptably smooth.

A gradient triangle is defined by its three vertices, each of which has a color consisting of three components: red, green, and blue (RGB). Each pixel within the triangle is colored in proportion to its distance from the three vertices, via linear interpolation. The three color components are interpolated separately.

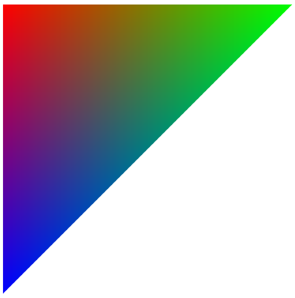

Figure 8: Gradient triangle for the primary colors red, green, and blue.

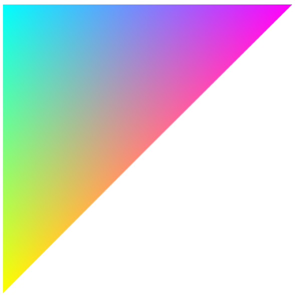

Figure 9: Gradient triangle for the secondary colors cyan, magenta, and yellow.

By arranging a pair of gradient right triangles so that they share a common hypotenuse, a gradient rectangle can be formed. Note that such a pair of gradient triangles can look very different from a true gradient rectangle. In a true gradient rectangle, each pixel is linearly interpolated using all four vertex colors. In comparison, the two gradient triangles are interpolated separately, and this tends to accentuate their shared hypotenuse, depending on which colors are used. The hypotenuse often glows like plasma, and this contributes significantly to the overall appearance of *TripLight* by adding structure. Sometimes mistakes are pleasant.

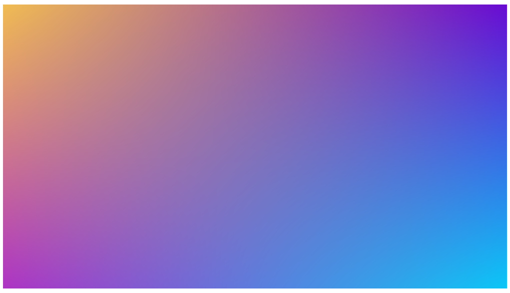

Figure 10: True gradient rectangle with four-way linear interpolation.

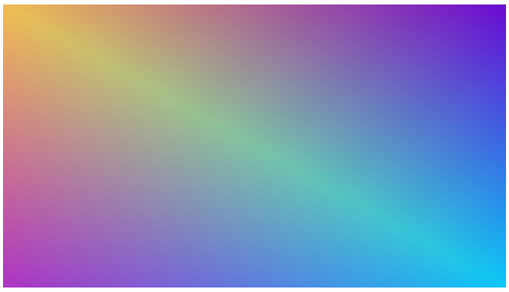

Figure 11: Gradient rectangle for the same colors, but composed of a pair of gradient triangles.

Larger-scale patterns can be created by aggregating multiple pairs of right triangles. At least eight repeating patterns are possible, of which the diamond pattern is the most visually satisfying.

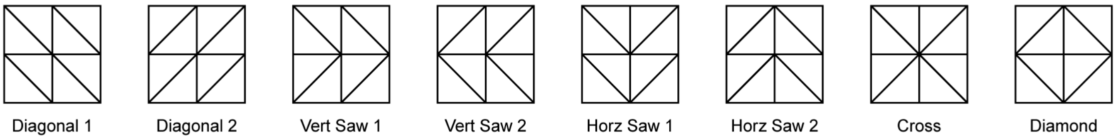

Figure 12: Repeating patterns made from pairs of right triangles.

Each color component is independently controlled by its own oscillator, thus each vertex uses three oscillators, one for each color component, and the total number of oscillators used is always three times the number of vertices. If the three oscillators controlling a color have different frequencies, color phasing occurs.

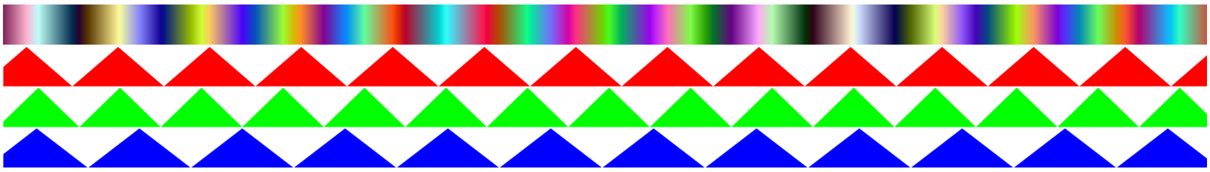

Figure 13: Color phasing: the lower three rows show triangle waves of different frequencies controlling the red, green and blue color components, while the top row shows the resulting color.

In previous works, each oscillator's period is explicitly specified, whereas *TripLight* only supports a single period for all oscillators. To this global period is added a randomized variance that potentially differs for each oscillator. The user specifies the range of this variance as a percentage. Thus if the global period is 100 and the variance is 15%, the actual periods vary randomly between 100 and 115. This use of randomness means that unlike its predecessors, *TripLight* is not purely phase-based, and consequently its behavior is difficult to predict.

Adagio for Color Fields

Adagio for Color Fields transforms *TripLight* into a synesthetic audiovisual installation by adding synchronized music. *Adagio* and *Plasmagon* evolved similarly, in both cases from a preexisting phase-based visual software. Technically, *Adagio* is a fork of the *TripLight* code that adds musical features while leaving the software's visual behavior unchanged.

TripLight supports many layouts of its gradient triangles, but *Adagio* is restricted to only one layout. The layout is diamond-shaped and consists of eight right triangles, having nine vertices between them. Since the color at each vertex has three components, each of which has its own oscillator, the total number of oscillators in *Adagio* is nine times three, or 27. The musical accompaniment is derived from only a subset of the vertices, specifically the four vertices at the corners of the diamond, hence the number of oscillators producing music is four times three, or twelve.

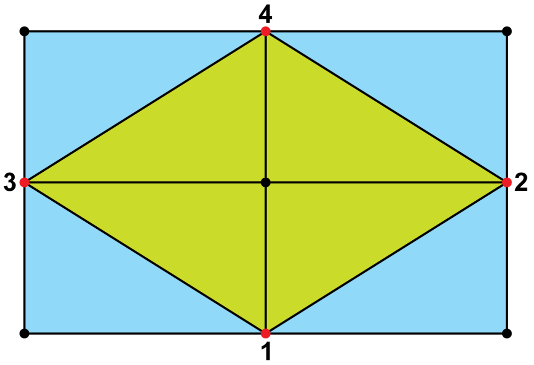

Figure 14: The diamond pattern, consisting of eight right triangles and nine vertices. The four vertices used by the music are highlighted in red.

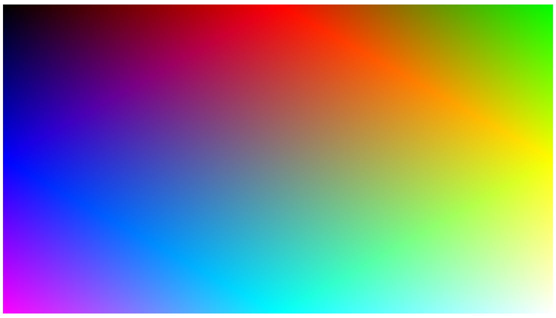

Figure 15: The diamond pattern with gradients. The nine vertex colors (left to right, top to bottom) are black, red, green, blue, gray, yellow, magenta, cyan, and white.

In *Adagio*, the music consists of twelve tones that continuously fade in and out. The fading is controlled by triangle waves, which are produced by twelve oscillators that also control the colors at the corners of the diamond, as explained above. The lowest three tones are mapped to the bottom corner, and the highest three tones are mapped to the top corner.

As in previous works, the oscillators all have different periods, and exhibit phasing as a result. The phasing proceeds identically in the music and the visual, and therefore elicits synesthesia. But unlike previous works in which the oscillator periods cover a wide range, in *Adagio* the periods vary by at most fifteen percent, hence the phases diverge and converge relatively slowly. This slow phasing tends to produce stately music, as is appropriate for an adagio.

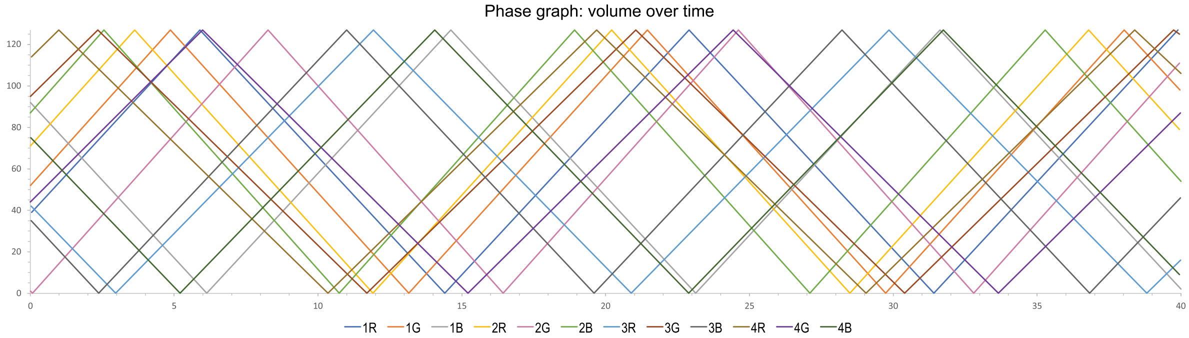

Figure 16: Typical phasing for the twelve tones used in *Adagio*. Each group of three tones maps to a vertex color.

As in *Plasmagon*, the tones used in *Adagio* don’t have fixed pitches; instead, they utilize a set of notes that changes over time. The notes are based on the cycle of thirds, which rearranges the diatonic scale so that every other note is skipped, for example C E G B D F A. This creates space for each tone to alternate between its normal note and the note immediately above it. The alternation is stealthy, meaning it occurs when the tone is silent.

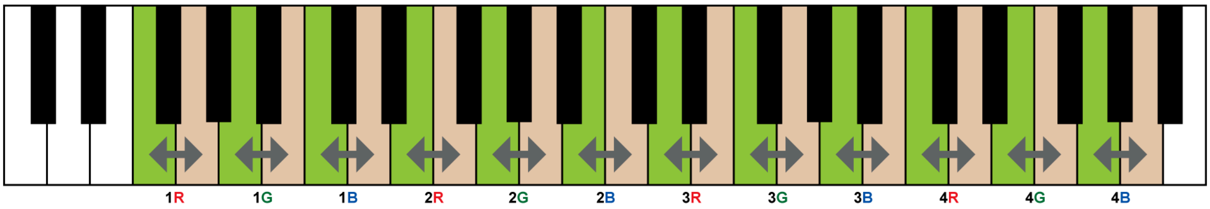

Figure 17: The twelve tones used in *Adagio* each alternate between a pair of adjacent notes. The normal note is green, and its alternate is pink. The labels indicate which vertex and color component each pair is associated with.

Since there are twelve tones, each having two possible states, the number of permutations is two to the 12th power, or 4,096. This is a considerable variety of chords. Harmonic variety is further increased by the phasing volume modulations, which continuously change the mix of tones. And for even more variety, the key changes periodically, cycling by fourths through all twelve keys. Thus *Adagio for Color Fields* unites gradations of music and color into a single synesthetic stimulus.

Glossary

convergence: when two or more oscillators that have different frequencies reach the starting point of their cycles simultaneously.

frequency: how often an oscillation happens, expressed as a number of cycles per second; the inverse of period.

generative art: art made entirely or partially by an autonomous system, which may operate randomly or according to predetermined rules.

gradient: an image that gradually blends two or more colors by interpolating between them.

oscillator: a repeating vibration, often a periodic waveform such as a sine wave.

period: how much time an oscillation takes, expressed as the duration of a cycle in seconds; the inverse of frequency.

phase: the current position of an oscillator within its cycle, relative to a defined starting point; representable as an angle.

phasing: the varying phase relationship between oscillators that have different frequencies.

phase art: art or music derived from phasing.

synesthesia: anomalous blending or fusion of the senses; a neurological condition in which information meant to stimulate one of the senses stimulates another one.

synesthetic art: art that elicits an experience of synesthesia in a general audience.